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A rating system based on present serviceability index (PSI) was used to rate and periodically rerate some 130 individual concrete saving projects of various ages. Indications are that many of the pavements will last 30 years or longer, but a few will fail in less than 20 years. Average ratings of new pavements, based on 20 projects, was about 4.3 PSI, which was disappointingly low.

Discussed in the report are various features affecting pavement performance, such as joints, cracks, and surface texture. An end result type specification for weakened plane joints, which has been successfully implemented on several projects, is included.

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PERFORMANCE OF PCC PAVEMENTS IN CALIFORNIA

FINAL REPORT
FEB. 1978

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

February 1978

FHWA No. D-5-42
TL No. 635254

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

PERFORMANCE OF PCC PAVEMENTS IN CALIFORNIA

Study made by . . . . Roadbed & Concrete Branch

Under the Supervision of . . . . D. L. Spellman

Principal Investigator . . . . J. H. Woodstrom

Co-Investigator . . . . B. F. Neal

Report Prepared by . . . . B. F. Neal

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

BFN:lb

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INTRODUCTION

"Pavement Performance" is a broad term meaning different things to different people. In this study performance was predominantly based on serviceability ratings or how well a pavement was performing its function as a riding surface for vehicular traffic. By making ratings on the same pavement periodically, it was hoped that the remaining service life could be predicted.

In addition to overall PCC pavement serviceability, some specific features were to be evaluated. These included transverse weakened plane joints and longitudinal joints between lanes on projects where tie bars had been omitted due to a design change. It was also planned to examine pavements with unusual performance characteristics, especially those performing exceptionally well.

The study was carried out concurrently with three other research projects concerning various areas of pavement performance. These were: (a) Pavement Faulting Study, (1,2,3,4) (b) a study of pavement texturing methods, (5) and (c) several experimental construction sections, the main one being continuously reinforced concrete pavement (6). Research on all projects was coordinated to prevent duplication of effort and to provide supplemental information to each.

The researchers have also worked closely with the Maintenance Division in the development of pavement evaluation methods, and are involved in the establishment of a Pavement Management System.

Due to the diversity of subjects to be discussed, this report is divided into five phases; (1) Transverse Weakened Plane

Joints, (2) Special Joint Treatments, (3) Pavement Ratings, (4) Evaluation of Design Changes, and (5) Related Research.

CONCLUSIONS

Based on the findings of this research, the Present Serviceability Index (PSI) is a satisfactory method of rating rigid pavements. A pavement which is rated 2.50 is considered to have approached a terminal state and is in need of rehabilitation. The PSI can be determined by a properly calibrated Road Meter. Corrections for cracking and patching are not deemed necessary until PSI nears the terminal stage, say about 2.75.

Ratings of 134 widely scattered projects indicate that many concrete pavements will last 30 years or longer, but some will require rehabilitation in less than 20 years.

The major distress symptom of pavements in California is faulting of the joints. Faulting leads to poor rideability and eventually requires corrective action. While some experimental actions are being taken to hopefully reduce the problem, further research is needed to develop more positive procedures, and to evaluate those corrective measures taken on an experimental basis.

A new end result type specification is resulting in better performing weakened plane joints. Less random cracking is occurring and there are fewer spalls and ravels of the concrete adjacent to the joint.

IMPLEMENTATION

The end result type specification for weakened plane joints has been implemented on several projects with satisfactory results. Inclusion in Standard Specifications is anticipated following a more complete evaluation.

The Office of Maintenance has used the pavement evaluation techniques acquired during this study to develop their biennial survey of all state highways. The groups working on the development of a Pavement Management System have also used the findings from this project in establishing "action" values for repair of rigid pavements, and in determining the type of repair suitable for a given pavement condition.

TRANSVERSE WEAKENED PLANE JOINTS

Two methods of forming weakened planes in concrete pavements have been used in California in recent years - inserting a strip of material in the fresh concrete, and sawing after the concrete has set and reached some minimum strength.

With the advent of slip-form pavers in the 1950's and the development of machines to pave two or more lanes at a time, placing inserts transversely by hand in the fresh concrete was no longer easy or practical. This led to the almost exclusive use of saws to form transverse joints. Slip-form equipment did readily lend itself to placing longitudinal strips to form joints between lanes, however. A vibrating inserter feeding a thin polyethylene strip from a reel located on the rear of the paver was used to form the longitudinal joint. Thus, forming longitudinal joints and sawing transverse joints became more or less standard practice.

In 1967, a machine capable of placing insert material transversely into the fresh concrete was developed and tried experimentally on two projects. Joints formed with the machine were considered satisfactory and specifications were changed to again allow use of inserts to form transverse weakened planes. Other machines were built and the method was used quite extensively.

In 1972, an evaluation was made of joints formed by sawing and by the insert method. A report (7) was made describing the advantages and disadvantages of each type. It was concluded that neither method was providing completely satisfactory joints and that changes in specifications were needed to assure better joint construction techniques. A draft of a proposed end result type specification was included in the report.

During meetings with both general and specialty contractors, numerous changes were made in the draft. One of the major changes was in connection with the problem at centerline when joint inserts were placed. A device on the inserter is supposed to cut the longitudinal tape before the transverse tape crosses. In many cases, the longitudinal tape was not cut but was pushed aside transversely and occasionally downward as well. This usually resulted in moderate to severe spalling. Since many longitudinal joints formed by insert did not perform as well as desired, it was decided to require sawing of the longitudinal joint and allow the contractor the option of either method for transverse joints. The revised specification (see Appendix A) was placed in 10 contracts for trial.

Not all of the contracts have reached the paving stage, but a check was made on those which had. It appears that contractors are about equally divided in their choice of transverse jointing methods. Resident Engineers were contacted to discuss any problems in administering the joint specification. Where the sawing method was utilized, engineers were very pleased and reported no problems. Inspection costs were reduced and on one project where numerous random cracks would normally be expected only 13 were found in 12 miles (19.3 km) of paving. This indicates that the contractor is making an effort to provide weakened planes at the optimum time. The corrective measures (epoxy injection) required for uncontrolled cracking provides an incentive for making that effort. Under previous specifications no such requirement existed for failure to prevent random cracking, although no payment was made for saw cuts made at cracked locations. The requirement for placing rope or other material in fresh saw cuts has also resulted in much cleaner joints when the project is completed.

Reactions from engineers on projects where joint inserts were used was not as favorable. Some depressions at the joints and edge slump occurred, especially on grades and superelevations. This required considerable inspection to determine the extent of faulty joint construction. By cooperation between the Engineer and the equipment manufacturer, joint construction was considerably improved before one project was completed. The cooperation of the Engineer meant more inspection than anticipated but obtaining a satisfactory product was considered preferable to penalizing the contractor and having unsightly joints. Obviously, there is still need for improving joint insert technology and providing better operator training.

Although there are minor problems with joint inserts, the desirable features of insert joints still remain. Cracking of pavement slabs is almost 100% controlled by inserts, and no reservoir is made to collect rocks and other debris which can lead to spalling. The corrective measures required for improper insert joint construction should provide incentive for improved technology and operator training.

The new joint specification is presently in Standard Special Provision form.

SPECIAL JOINT TREATMENTS

During discussions of joints with contractors, it was their recommendation that joints be sealed to improve performance. A proposed experiment was developed and accepted by the State for implementation on a project in the San Francisco Bay area. The proposal, with the contractor's cost estimate, was as shown below. The project was the construction of an 8 lane freeway on new alignment.

PROPOSED EXPERIMENTAL SECTIONS

Each section should be approximately 1000-ft. (305 m) or 65 transverse joints in length. Station limits shown are approximate.

Transverse Joints Only

1. Install 1/4 in. or 5/16 in. (6.5 or 8 mm) cotton or fiber welt cord in top of the sawed transverse weakened plane joint. Placement of the cord shall follow the sawing operation closely enough to prevent drying of the concrete exposed by sawing. Spraying curing compound in the saw cut will not be required. Before pavement is opened to traffic, cord is to be rolled to the bottom of the saw cut and left in place. (Station 1085 to 1075 SB.)

2. Same as No. 1, except substitute a closed cell neoprene cord in lieu of the cotton or fiber welt material. (Station 1123 to 1112 SB.)

3. Install cord after sawing as in No. 1 above. Between 3 and 7 days after sawing, roll cord to bottom of joints, blow out joints with compressed air and apply joint seal material meeting Federal Specification SS-S-1401. (Station 1145 to 1135 SB.)

Longitudinal and Transverse Joints

4. Widen and deepen saw cuts to 3/8 in. and 1-1/4 in. (9.5 and 32 mm) dimensions respectively. Sandblast and clean saw cuts, install 1/2 in. (12.5 mm) diameter expanded closed cell neoprene rod in bottom of saw cut, prime sides and seal with State Specification 701-56-39 polyurethane joint sealant.

Longitudinal joints are to receive the same treatment as the transverse joints. (Station 1135 to 1145 NB.)

5. Widen and deepen saw cuts and clean as in No. 4. Install 1/2 in. (12.5 mm) diameter cotton or fiber welt cord in bottom of saw cut and seal with Federal Specification SS-S-1401.

Longitudinal joints are to receive the same treatment as the transverse joints. (Station 1113 to 1123 NB.)

6. Same as No. 5, except joint sealant specifications modified as follows:

Test		Requirement
A.	Compatibility with asphalt	Waived
B.	Flow at 150°F (66 C)	No flow
C.	Resilience. All samples cured 96 hours at 75±7°F (24±4 C). Oven aged sample cured 24 hours extra at 150±2°F (66±1 C)	50% minimum
D.	Bond to concrete, failure	1/4 in. (6.5 mm) maximum on all samples
E.	Artificial weathering test. Interim Federal Specification SS-S-00200C, paragraph 4.3.3.14	Shall not flow, show tackiness, presence of an oil-like film or reversion to a mastic-like substance, formation of surface blisters either intact or broken, form internal voids, surface crazing or cracking, hardening or loss of resilient rubber-like properties.
F.	Penetration	1.30 centimeters, max.

In addition, the joint sealant shall be a liquid which remains fluid until after it has been heated to approximately 250°F (121 C) and allowed to cool. (Station 1075 to 1085 NB).

7. Install 5/16 in (8 mm) preformed elastomeric joint seal conforming to the specifications of ASTM Designation: D2628. Joint grooves shall be cut to a width so as to accept the 5/16 in. (8 mm) seal at the time of sealing, based on the recommendation of the seal manufacturer. Joints shall be sandblasted and cleaned before seal installation.

The joint seal shall consist of a multi-channel, nonporous, homogenous material furnished in a finished extruded form. Immediately prior to installation, a combination lubricant and adhesive shall be applied to the sides of the sealant and to all vertical surfaces of the concrete which will be in contact with the seal. The lubricant-adhesive and rate of application shall be as specified by the manufacturer of the seal.

Longitudinal joints are to receive the same treatment as the transverse joints. (Station 1057 to 1067 SB.)

8, 9. On a portion of the project where plastic inserts were used to form transverse joints, saw cut through the inserts to form a 3/8 in. by 1-1/4 in. (9.5 by 32 mm) reservoir and repeat procedures of Sections 4 and 6.

Longitudinal joints are to receive the same treatment as the transverse joints. (No. 8, Station 1170 to 1180 NB; No. 9 Station 1180 to 1170 SB.)

10. Install plastic drain pipe along the outer edge of the PCC pavement. Pipe shall consist of nominal 1-1/2 in. (38 mm) PVC Schedule 80, Type II 2110 pipe conforming to the specifications of ASTM Designation: D1785, and shall be National Sanitation Foundation approved. Slotted pipe shall be used in 10-ft. (3 m) lengths with external and internal flush joints, one male and one female connection on each end. The pipe shall have two rows of slots cut circumferentially on two of the third points 120 degrees apart and the average configurations shall be 42 slots ± 1 slot per row per foot, using 0.020-inch (0.5 mm) slots.

Prior to installation of the pipe, the CTB adjacent to the outer edge of pavement shall be cleaned of waste concrete and other debris. The pipe shall then be solvent welded and placed next to the pavement with slots down. At 100-ft. (30.5 m) intervals, tee fittings shall be placed and approximately 15 ft. (4.5 m) of unslotted, unperforated PVC pipe placed to provide drainage to the outside of the shoulder. The end of this pipe shall be fitted with swing check valves to prevent the entry of small animals. The ends of the 1000-ft. (305 m) length of drain shall be plugged. Fittings shall be of rigid PVC. (Station 1065 to 1055 NB.)

Section 10 with the drain pipe was proposed by the State as part of the research into pavement faulting problems. Joint seals are not considered 100% effective in keeping all water from under the pavement, but a drainage system might remove water before serious damage could result. The drain has worked effectively for three years. Flow measurements during and after rains indicate that water was being removed at an average rate of over 60 gallons an hour (63 ml/s), and drainage stops within an hour of cessation of rain.

Test sections were installed essentially as proposed. No problems were encountered in installations of sections 1 and 2, but a number of the neoprene rods broke and were dislodged, evidently from being over stretched. In pouring sealants, some joints were overfilled, which is undesirable, but the major problem was in maintaining clean joints prior to sealing. Strong winds blew dust and sand almost every day. This created bonding problems when adhesives were used and at joint intersections where sealant was placed in one direction, and then later in the other direction.

In sections 8 and 9, joints in a pavement constructed about 2 years previously but not opened to traffic, were to be widened by saw cuts and sealed. Both longitudinal and transverse joints in this project were formed by the insert method. Sawing of

ESTIMATED COSTS OF EXPERIMENTAL SECTIONS

Exp. Sect. No.		Cost Per 1000 Lineal Feet of Pavement, 48' Wide Transverse	Longitudinal
1.	$0.035 to $0.045 per lin. ft.	$ 145	$ 0
2.	$0.06 to $0.07 " " "	230	0
3.	$0.15 to $0.20 " " "	650	0
4.	$0.50 to $0.60 " " "	1950	1800
5.	$0.38 to $0.48 " " "	1560	1440
6.	$0.40 to $0.50 " " "	1625	1500
7.	$0.50 to $0.60 " " "	1950	1800
8.	$0.50 to $0.60 " " "	1950	1800
9.	$0.40 to $0.50 " " "	1625	1500
10.	$0.50 to $0.60 " " "	90	600
Tee fittings, 10 at $2 each			20
Swing check valves, 10 at $8 each		80	
	Totals	$11855	$10460
	Grand Total	$22315	

NOTE: 1 ft = .305 m

the old concrete to the width and depth required was difficult and was further complicated by misalignment of the longitudinal joint where the tape had been displaced by the transverse joint inserting machine. A special saw was required to follow the crack at those locations. Due to the problems and increased cost involved, the test lengths were cut in half and both sections placed on the southbound roadway. In addition to the proposed treatments in this area, the outer shoulder joint was widened and sealed in half of each section. This was done to determine if performance of shoulder joints could be improved. This is a problem area on many pavements and pumping and ejection of fine material is often noted at those joints.

Since the experimental construction was done on a going project by Contract Change Order, payment was based on materials and labor costs rather than bid or negotiated price. Following are the actual costs of each section.

Section 1	Cotton rope rolled to bottom of joint, $0.08 per lin. ft. (1 ft. = 0.305 m)
Section 2	Neoprene rod rolled to bottom of joint, $0.15 per lin. ft.
Section 3	Normal saw cut sealed with Sealflex 1401, $0.30 per lin. ft.
Section 4	Widened saw cut sealed with Sealflex 39, $1.15 per lin. ft.
Section 5	Widened saw cut sealed with Sealflex 1401, $0.79 per lin. ft.
Section 6	Widened saw cut sealed with Superior 444, $1.01 per lin. ft.
Section 7	Widened saw cut sealed with compression seal, $0.51 per lin. ft.
Section 8	Saw old PCC and seal with Sealflex 39, $1.06 per lin. ft.
Section 9	Saw old PCC and seal with Sealflex 1401, $0.91 per lin. ft.

These costs are not considered indicative of those based on bid prices due to the relatively short lengths of each section and some of the problems which arose. They are interesting in that 8 of 9 sections cost approximately twice the estimated amount. The preformed compression seal in Section 7 was the only one within the Contractor's estimate.

There is no detectable difference in joint performance after three years. However, all sections are beginning to show slight faulting. While there are a number of seals with adhesion (bond to concrete) failures, this was expected due to the blowing dust and sand. A few cohesion failures were found in joints sealed with the Sealflex materials. All failures were difficult to find except by very close inspection. It is planned to continue monitoring all sections to determine the effect on both joint performance and overall pavement performance.

PAVEMENT RATINGS

A number of rating systems were considered at the beginning of the project. The present serviceability concept developed during the AASHO Road Test seemed to offer a practical method and one which is widely accepted by many agencies. Present serviceability is defined as "the ability of a specific section of pavement to serve high-speed, high volume, mixed (truck and automobile) traffic in its existing condition." The Present Serviceability Index (PSI) is "a mathematical combination of values obtained from certain physical measurements..." the result of which can be used on a convenient numeric scale.

Studies made at the AASHO Road Test (8) have shown that about 95 percent of the information about the serviceability of a pavement is contributed by the roughness of its surface profile. To measure this roughness, a road meter of the type developed by Brokaw of the Portland Cement Association was used. The CHLOE Profilometer developed for use in the AASHO Road Test was used as a correlation device. Occasional checks are made on pavements scheduled for rehabilitation because of roughness (determined subjectively) and a PSI rating of 2.50 has been found to correlate well with "terminal" condition of a pavement.

Except in rare instances, the outer or travel lane always develops roughness first. When this lane reaches a terminal state, some type of rehabilitation is necessary, regardless of the condition of the interior lane or lanes. Because of this, only outer lanes were rated in the study.

To develop performance trends, pavements of various ages were selected for rating, ranging in age from new to 22 years. One pavement 44 years of age was found to be still serving heavy traffic and the PSI was below 2.0. When a project was selected, the paving limits were first established, and then, in most cases, the entire project was rated in both directions of travel. Although rating was on a post mile basis, an average project rating was also established. Periodic reratings were made, usually about once each year. A total of 134 projects have been rated and rerated 2 to 5 times each. The projects represent over 1300 lane miles (2100 km) of rated PCC pavements covering all areas of the State.

The formula for calculating PSI includes a provision for reduction for cracking and patching. There is some disagreement depending upon climate, traffic and level of

with this concept unless considerable judgement is used. Certainly corner breaks and third stage cracking where cracks are interconnected are indications of structural failure, but transverse cracks near midslab may not detract from performance at all. Some patches may have been placed to cover up broken slabs but others may be only to improve riding quality where localized settlements have occurred. The latter areas may be mudjacked at a later date to restore original profile. While cracking and patching records were obtained on many projects, trends are based on ride serviceability only. It was decided that, except in rare cases, cracking and patching need not be checked until ride serviceability approaches a PSI of about 2.75.

Figure 1 shows a line of best fit for PSI (based on ride only) at various ages for all pavements rated. For ages to 15 years, the number of projects for individual years varied from 14 to 39, and for ages 16 through 23 years, from 7 to 13. It should be kept in mind that the plot represents projects in which both traffic and pavement thickness are important variables. Variations in strengths of pavements or bases can also affect performance. Thickness of pavements constructed in the past 10 years are mostly 0.75 ft. (0.23 m), but a number of the older ones are only 0.67 ft. (0.2 m). On the newer pavements the outer, or travel lane, is often thicker than the inner lanes.

A straight line projection of the best fit curve would indicate that half the projects rated should last well over 30 years before repair is needed. Usually, however, when a certain stage is reached, the deterioration rate increases greatly, so the average terminal age cannot be reliably predicted from available data. It is also expected to vary widely seem that this material would be subject to pumping which leads to faulting, but possibly it provides good drainage of water and is conducive to better performance.

B-1 is a pavement in the San Francisco Bay area where ground water in cut areas caused slides and slight upheaval of the pavement in some areas. Although B-2 was looked at closely, no explanation was found for the below average performances. The project is on basically tangent alignment with shallow cuts and shallow fills. The outer lane in each direction was ground to remove faulting after 17 years of traffic, restoring the ride PSI to 4.35. An experimental drainage section was installed to see if the recurrence of faulting could be prevented or delayed. Projects B-3 and B-4 have received an AC overlay and B-5 is being ground. The basic problem with the latter 4 projects was advanced faulting.

In other examples of abnormal behavior, two projects were found where a great amount of transverse cracking occurred within 2 years after opening to traffic. Both are in what might be called high desert, but about 500 miles (800 km) apart. In California, joints are spaced on a repeat pattern of 13, 19, 18, and 12 feet (4.1, 5.8, 5.5, and 3.7 m). On a large portion of each project, practically all of the longer slabs had cracked transversely near the center. No explanation was found for this behavior. Both projects have good riding characteristics and no problems have developed in performance otherwise.

One of the problems often encountered in the investigation of older pavement performance is the difficulty in obtaining information on specific construction materials, techniques, procedures and problems that may have occurred during construction. Job records are kept only for a limited time after completion, and most of the people involved in the construction have since retired.

An objective of this study was to establish procedures and forms to collect laboratory and pavement construction data during construction of selected jobs. A form was made and modified under use on 20 construction projects (see Appendix B). In addition to obtaining information for the form, at least one day was spent observing the paving operation, making notes of all existing conditions at the time of observation, and taking photographs of pertinent features. If an investigation is later needed, the collected data should provide valuable aid.

It was planned that, under another project, a computerized data storage and retrieval system would be developed. Storing the information collected before and during paving, then recording all maintenance activities, would provide a good history of each project and greatly facilitate pavement evaluation. The planned system has not been developed. The laboratory is still filling in forms for each paving project with as much information as can readily be obtained by phone, but complete data is difficult to obtain in many cases. By working through the Office of Maintenance, a start has been made in improving the reporting of maintenance costs on PCC pavements. This should aid in the determination of lifetime costs of pavements and provide more accurate economic analyses of pavement types.

EVALUATION OF DESIGN CHANGES

About 1962, a few pavements were constructed without placing tie bars between lanes. There appeared to be no problems from this omission and since about 1964, all pavements have been constructed in this fashion. In 1970, it was noted that lane separation was occurring in some areas. To determine the extent of the problem, it was proposed to use the existing micro-log system in which all state highways are photographed periodically at distance intervals of about 53 feet (16 m). However, the clarity of the photographs is only good for about half the 53 foot distance covered in the pictures, and the angle of lighting is often wrong for photographing longitudinal cracks, or joints. In a comparison between the length of lane separations as determined (as well as possible) from micro-log films and as measured by a special odometer in a car, the micro-log was judged inadequate. The micro-log system was abandoned for this purpose.

The major areas affected by lane separation were found to be portions of Interstate 5 in the Sacramento and San Joaquin Valley regions. Expansive soils are a problem in these regions and are believed to be responsible for the movement causing separation of lanes up to 2 inches (50 mm). After watching these openings for the past 7 years, it appears they are stabilized. No changes in width have been noted and adjacent pavement has not developed the problem. One project in the high desert developed large openings between lanes, but the cause, fill settlement, was easily determined. It is doubtful that tie bars between lanes could have held the pavement together under existing conditions. In summary, the open joints, while undesirable, are not causing noticeable adverse pavement performance, but have required some maintenance effort.

At about the same time slip-form paving became standard practice in California, the cement treated base was widened one foot (0.3 m) on either side of the pavement. This design change was intended to serve two purposes; first, it would provide a more solid and smooth base for the paver tracks, and second, it would reduce subgrade pumping. It is considered to have served well for both purposes. However, some pumping still occurs. This results in removal of fines from the shoulder and subsequent settlement, as well as opening up the pavement shoulder joint. It was planned that the micro-log films be used to determine the extent of this problem also, but for the same reasons previously mentioned it was not possible to do so. Though not determined quantitatively, the problem was found to be extensive and not limited to any specific area of the State. It was found that filling joint openings and patching depressed shoulders probably requires more maintenance effort than any other repair operation on PCC pavements.

RELATED RESEARCH

Faulting

The most common distress on California's rigid pavements (unreinforced), and the one for which rehabilitation is most often required, is faulting (step-off) of joints and cracks. In concurrent research into the faulting problem, a total of 4 reports have been published (1,2,3,4) and a final report is in preparation. The first two cover field investigations, describe the causes of faulting, and have some suggestions for design changes to alleviate the problem.

The third report describes construction of lean concrete base (LCB) on two projects. LCB can be placed and vibrated by a slip-form paver and is considered superior, at least under PCC, to cement treated base (CTB). A specification has been incorporated into a number of projects which allows a contractor the option of using either type of base. Hopefully, the use of LCB will improve pavement performance by providing a harder base surface, and eliminating a major source of fines which contributes to faulting.

The fourth report is an evaluation of diamond blade grinding to restore riding quality of faulted pavements. It was shown that the service lives of several pavements have been extended a significant amount by grinding to reduce or eliminate step-off. At least one project is serving well 12 years after grinding, although faulting is recurring. The rehabilitation of pavements by grinding is considered a desirable alternative to overlaying in many cases, and several grinding contracts have been awarded recently. A different type of planer (Roto Mill) has recently been introduced which may also make grinding of faulted pavements a viable strategy. Reports indicate, however, that the type of cutting used causes extensive joint spalling.

Under new research, the faulting phenomenon will be studied under controlled laboratory conditions. Faulting is to be induced in model slabs with automated repetitive loading, then various methods evaluated that are designed to prevent or reduce further faulting. The primary objective is to develop procedures to stop faulting on existing pavements. The reduction or elimination of faulting will greatly increase pavement service life.

Pavement Texturing

In a forthcoming report (5) experiments in texturing pavement surfaces will be described. Specifications were developed and have now been adopted which require longitudinal grooves to be formed by metal tines, preceded by a broom or burlap drag texture. This is expected to result in longer lasting texture and reduce skidding accidents by providing better vehicle control.

Experimental Construction

Several experimental features were incorporated on one construction project. The predominant feature was continuously reinforced concrete pavement (CRCP) constructed on various sections for a total distance of just over 9 miles (14.5 km). Reinforcement of the CRCP included longitudinal bars only, both longitudinal and transverse bars, and welded wire fabric. Other experimental sections included joints at about half the normal spacing, extra strength concrete, increased pavement thickness, and a concrete base. The construction of these features are described in a previous report (6). All experiments were considered as possible methods of improving pavement performance. A final report on the project is being prepared.

REFERENCES

1. "California Pavement Faulting Study," Transportation Laboratory report, Jan. 1970.

2. "Faulting of Portland Cement Concrete Pavements," Transportation Laboratory report, Jan. 1972.

3. "California Trials With Lean Concrete Base (LCB)," Transportation Laboratory report, Feb. 1976.

5. "Improve Portland Cement Concrete Wearing Surfaces," Transportation Laboratory report to be published.

6. Recent Experimental PCC pavements in California," Transportation Laboratory report, June 1973.

7. "A Comparison of Transverse Weakened Plane Joints Formed by Sawing and by Plastic Insert," Transportation Laboratory report, Sept. 1973.

8. "The Pavement Serviceability-Performance Concept," W. N. Carey, Jr. and P. E. Irick, HRB Bulletin 250, Jan. 1960.

10-1.20 CONCRETE PAVEMENT.--Portland cement concrete pavement shall conform to the provisions in Section 40, "Portland Cement Concrete Pavement," of the Standard Specifications and these special provisions.

The concrete for pavement shall contain a minimum of 517 pounds of portland cement per cubic yard, except that after testing the proposed aggregates the Engineer may order an increase or decrease in the cement factor in accordance with the requirements in Section 40-1.01, "Description," of the Standard Specifications.

If an increase or decrease in the specified quantity of portland cement is ordered by the Engineer, the compensation to the Contractor will be increased or decreased on the basis of a firm price of $42.00 per ton of cement.

Section 40-1.08, "Joints," of the Standard Specifications is amended to read:

> Joints in pavement will be designated as longitudinal and transverse contact joints, transverse expansion joints and longitudinal and transverse weakened plane joints, and shall be constructed as shown on the plans and in accordance with the following provisions.
>
> All transverse joints shall be constructed at the angle to the pavement centerline shown on the plans, and faces of all joints both transverse and longitudinal shall be normal to the pavement surface except as specified herein.
>
> Joints shall be maintained clean and free of all foreign material, except filler material, at all times prior to acceptance of the contract.
>
> Straight tie bars shall be either deformed reinforcing steel bars conforming to ASTM Designation: A 615, Grade 40 or 60, or deformed reinforcing steel bars conforming to ASTM Designation: A 616, Grade 50 or 60.

Section 40-1.08B, "Weakened Plane Joints," of the Standard Specifications is amended to read:

> Longitudinal weakened plane joints shall be constructed at traffic lane lines in multilane monolithic concrete pavement by the sawing method. Transverse weakened plane joints shall be constructed either by the sawing method or by the insert method at the option of the Contractor.
>
> There shall be 4 transverse weakened plane joints in each 62 linear feet of pavement placed, exclusive of approach slabs, pressure relief joints, and end anchors, spaced as shown on the plans. All transverse weakened plane joints shall be located within a spacing tolerance of plus or minus one foot, except as otherwise provided.
>
> No transverse weakened plane joint shall be constructed within 5 feet of another transverse joint under any circumstance. If the planned spacing of transverse weakened plane joints would result in locating a transverse weakened plane joint within 5 feet of another transverse joint, the transverse weakened plane joint shall be relocated so that it is not within 5 feet of said transverse joint.
>
> Final alignment of transverse weakened plane joints shall conform to that shown on the plans. Final alignment of longitudinal weakened plane joints shall be uniformly parallel with the pavement centerline. Final alignment of both transverse and longitudinal weakened plane joints shall be free of local irregularities which exceed 0.1-foot measured from either side of a 12-foot straight line, except for normal curvature of centerline with respect to longitudinal joints.

Volunteer cracks are all cracks and all portions of cracks that are not coincident with constructed joints.

Volunteer cracks and spalls shall be repaired as provided in Section 40-1.08B (3), "Repair of Cracks and Spalls and Ravelling and Tearing."

40-1.08B(1) SAWING METHOD.--The sawing method shall consist of cutting a groove in pavement with a power driven concrete saw. Sawed grooves for longitudinal and transverse weakened plane joints shall be cut to a minimum depth of 0.17-foot and to the minimum width possible with the type of saw being used, but in no case shall the width exceed 0.02-foot.

The exact time of sawing longitudinal and transverse weakened plane joints shall be the Contractor's responsibility. Sawing transverse weakened plane joints shall be completed within 72 hours following paving. Sawing longitudinal weakened plane joints shall be completed before opening the pavement to any traffic. The Contractor shall exert every possible effort to prevent volunteer cracking. To achieve this, the sequence of sawing may be varied, water may be applied to cool the pavement surface after pigmented curing seal is placed, or other measures not detrimental to the pavement surface may be utilized.

In lieu of conflicting provisions in Section 90-7.02, "Curing Pavement," the Contractor shall bear the cost of applying cooling water, after pigmented curing seal has been placed, to prevent volunteer cracking.

Where a transverse volunteer crack occurs prior to sawing, and any point on the crack is within 5 feet of a planned transverse weakened plane joint location, the transverse weakened plane joint shall be relocated as specified herein. Relocation shall be the minimum amount necessary, but in no event shall it exceed 14 feet. If a relocation not exceeding 14 feet is insufficient to locate the transverse weakened plane joint so that it is not within 5 feet of that transverse volunteer crack or other transverse joint or crack, at any point in the length of joint, the weakened plane joint shall be located at the planned location and the volunteer crack shall be injected with epoxy as provided in Section 40-1.08B(3), "Repair of Cracks, Spalls, Ravelling and Tearing." Such relocation shall be made without otherwise altering the location of remaining transverse weakened plane joints except where they too would be within 5 feet of pre-existing transverse volunteer cracks.

At the Contractor's option, joint filler material may be installed in the sawed groove for longitudinal and transverse weakened plane joints to keep foreign materials out of the joints. The filler material used shall be of such character as to not react adversely with chemical constituents of the concrete or cause physical damage to the pavement. Should the Contractor install joint filler material immediately after sawing the joint which is of such composition as to prevent excessive loss of moisture from concrete adjacent to the joint, during the 72 hours following paving, spraying the sawed joint with additional curing compound as provided in Section 90-7.02, "Curing Pavement," will not be required. If absorptive filler material is used, it shall be thoroughly moistened either before or immediately after installation in the sawed groove.

Filler material may be left in sawed joints upon acceptance of the contract providing the material is not such as to constitute a physical hazard should it work out of joints after opening the pavement to public use.

When filler material is rope, or similar material which does not fill the entire depth of sawed groove, it shall be depressed not less than 0.04-foot below the pavement surface before the pavement is opened to public traffic, but not less than 72 hours following paving.

Excessive ravelling or tearing of concrete adjacent to saw cuts, caused by sawing when concrete is too green, shall be repaired as provided in said Section 40-1.08B(3). Excessive ravelling or tearing shall be defined as an accumulation of more than one foot of ravelling or tearing which exceeds 0.04-foot in width, exclusive of the saw cut, in a 12-foot lane, or an accumulation of more than three feet of ravelling or tearing which exceeds 0.02-foot in width, exclusive of the saw cut, in a 12-foot lane.

40-1.08B(2) INSERT METHOD.--The insert method consists of placing an insert of bond breaking material in freshly placed concrete.

Joint inserts shall be continuous strips of plastic or other material which will not react adversely with chemical constituents of concrete or bond with the concrete.

Insert material shall be placed by means of a mechanical installation device which shall vibrate the plastic concrete sufficiently to cause an even flow of concrete about the insert. After installation of joint material, concrete in the joint area shall be free of segregation, rock pockets, and voids. In addition to the straightedge requirements in Section 40-1.10, "Final Finishing," the finished pavement surface at transverse insert joints will be tested by means of a straightedge 4 feet long laid on the pavement parallel to centerline with its midpoint at the joint. A minimum length of 10.5 feet in any 12-foot length of joint shall not vary from a true plane enough to permit a 0.005-foot thick shim 0.25-foot wide to pass under the lower edge of the 4-foot straight edge at any point along its length.

Pavement exceeding these tolerances, when tested within 10 calendar days following placement of concrete, shall be corrected by grinding until the surface does conform thereto. Pavement surface at transverse insert type joints conforming to all requirements in Section 40-1.10, "Final Finishing," but failing to conform to the 4-foot straight edge requirements may be corrected by grinding parallel to joint alignment. The provisions in said Section 40-1.10 for grinding to neat rectangular areas will not apply to grinding done to comply with 4-foot straight edge requirements. Such grinding parallel to the transverse joint need not be extended in each lateral direction to the nearest lane line or edge of pavement nor in each longitudinal direction so that the grinding begins and ends at lines normal to the pavement centerline.

Insert material shall have a minimum thickness of 0.013-inch and a width of not less than 0.16-foot nor more than 0.18-foot. Inserts shall be installed so that the top edge is not above nor more than 0.03-foot below the finished concrete surface. Inserts shall not be deformed more than 15 degrees from a position perpendicular to the plane of the pavement surface during installation or subsequent finishing operations performed on the concrete.

Splices in joint insert material will not be permitted.

40-1.08B(3) REPAIR OF CRACKS, SPALLS, RAVELLING AND TEARING.--Volunteer cracks amd spalls, and ravelling or tearing at sawed joints, shall be repaired as provided in this Section 40-1.08B(3) prior to opening the pavement to public traffic.

All volunteer cracks, except as otherwise provided, that occur during the 10 calendar days following placement of concrete shall be repaired by injecting the entire length of the cracks with epoxy under pressure. Volunteer cracks not requiring injection with epoxy shall be limited to single continuous volunteer cracks without branch or connecting cracks that conform to either of the following conditions:

(1) Begin or end at a longitudinal joint or edge of pavement and are not within 5 feet, at any point along the length of crack, of a transverse joint or other volunteer crack that has not been injected with epoxy.

(2) Do not begin or end at a longitudinal joint or edge of pavement and are not; (a) within 5 feet, at any point along the length of crack, of any transverse joint; and (b) within one foot, at any point along the length of crack, of any longitudinal joint, edge of pavement, or other volunteer crack that has not been injected with epoxy.

Where volunteer cracks cross or are partially coincident with sawed joints either protective measures shall be taken to prevent entry of epoxy into saw cuts sufficient to reduce specified groove depth or at the option of the Contractor, accumulations of epoxy in saw cuts shall be removed by resawing to the specified depth prior to opening the pavement to any traffic, but no later than 72 hours after injecting the epoxy.

Epoxy injection shall be completed within 90 working days after pavement is placed.

In making epoxy injection repairs, a surface seal shall be applied to prevent escape of epoxy and entry ports shall be placed at intervals to allow filling the entire length of crack. Surface seal material, and injection procedures, shall be such as to prevent damaging the texture and appearance of the pavement surface after opening to public traffic. Epoxy shall be injected using in-line mixing equipment. Pressure pots shall not be used. Epoxy shall conform to State Specification 731-80-27.

The Contractor shall provide cores of epoxied cracks at the rate of five relatively evenly spaced cores for each 150 linear feet of epoxied crack. If the total length of cracks to be epoxied exceeds 150 linear feet, the rate of coring may be reduced to one core for each additional 100 linear feet of epoxied crack provided the Contractor's methods and equipment are producing satisfactory results. Cores shall extend through the entire depth of pavement and include the full depth of crack. Location of cores will be determined by the Engineer. Cracks where epoxy has penetrated to less than 80 percent of the crack depth shall have additional epoxy injected until a minimum of 80 percent of the crack depth has been filled. Such cracks may require additional cores for verification as determined by the Engineer.

All holes resulting from coring shall be completely filled with concrete of the same quality as used to construct the pavement.

Any joints or volunteer cracks with spalls more than 0.05-foot deep which exceed 0.04-foot in width and 0.3-foot in length that occur before pavement is open to public traffic, and sawed joints with excessive ravelling or tearing shall be repaired, but only after removing all weak fractured concrete and cleaning surfaces to receive the patch. A prime coat of epoxy resin binder, State Specification 701-80-46, shall be applied to the area to be patched using a stiff bristled brush. A patch consisting of portland cement concrete or epoxy resin concrete (or mortar), at the Contractor's option, shall be applied immediately following the application of the prime coat. An insert, or other means, shall be used to prevent bonding both sides of planned joints together.

The last paragraph in Section 40-1.13, "Measurement," of the Standard Specifications is amended to read:

No measurement or separate payment will be made for longitudinal joints or for transverse weakened plane joints.

Section 40-1.14," Payment," of the Standard Specifications is amended to read:

Items of work, measured as specified in Section 40-1.13, "Measurement," will be paid for at the contract prices paid per square yard for the specified thickness of concrete pavement.

Full compensation for tie bars placed in transverse contact joints will be considered as included in the contract price paid per square yard for concrete pavement and no additional compensation will be allowed therefor.

The above prices and payments shall include full compensation for furnishing all labor, material (including portland cement), tools, equipment, and incidentals, and for doing all the work involved in constructing the portland cement concrete pavement, complete in place, as shown on the plans, and as specified in these specifications and the special provisions, and as directed by the Engineer, including:

(1) The removal, replacement and payment for deficient thickness as provided in Section 40-1.135, "Pavement Thickness."

(2) Furnishing and installing filler material in sawed weakened plane joints to keep out foreign material.

(3) Repair of volunteer cracks, spalls, and ravelling or tearing at sawed joints as provided in Section 40-1.08B(3), "Repair of Cracks, Spalls, Ravelling and Tearing."

(4) Providing cores of epoxied cracks, and filling core holes, as provided in Section 40-1.08B(3), "Repair of Cracks, Spalls, Ravelling and Tearing."

APPENDIX B

PCC PAVEMENT INFORMATION SHEET

Contract No. ______________________ Date Awarded ______________

Road Designation ____

Description ____

R.E. ____________________ City ______________ Phone ________

Prime Contractor ____

Paving Contractor ____

Est. Paving Date ________ as of ________; ________ as of ________

R-30 Dated ____________________ Received ____________________

Aggregate Source: 1-1/2 x 3/4 ________________________________

1 x 4 ________________________________

Sand ____________________________________

Brand of Cement ____

Cement Content per Special Provisions ________________________

Cement Content Recommended: __________________ Used __________

Was Test Program made for this Project? _______________________

Date of Test Program Used ___________________________________

Quantities of Concrete ______________ SY ______________ thick

__________ SY __________ thick, __________ SY __________ thick

Comments: ____

____

Field Information: Actual paving dates __________ to __________

Type of Plant ____

Brand & Size of Mixers ______________________________________

Type of Paving Machine ______________________________________

Type of Finishing Operation __________________________________

Type of Weakened Plane Joints ________________________________

Comments: ____

____

____

Attach: Index Map, Typical Sections, and Photographs